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SIMULATORS FOR TRAINING AND PROFIT

CHARLES O. HOPKINS

ARL-76-10/AFOSR-76-5
JULY 1976

PREPARED FOR

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

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Technical Report

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FOREWORD

This paper was prepared as a Technical Note to support the "Future Planning" session of the Symposium on the Future of Simulators in Skills Training. The symposium was held as a part of the First International Learning Technology Congress and Exposition, sponsored by the Society for Applied Learning Technology, Washington, D.C., 22-24 July 1976. The material concerning transfer effectiveness ratio and the rationale for cost effective simulator selection and use is from research tasks comprising a part of the Aviation Research Laboratory program sponsored by the Air Force Office of Scientific Research under Contract No. F44620-76-C-~~0105~~ 0009. Dr. Charles E. Hutchinson was monitor of the contract.

SIMULATORS FOR TRAINING AND PROFIT

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ABSTRACT

The use of simulators for training and profit is discussed in terms of the concept of cost effectiveness. Increased degree and fidelity of simulation require greater equipment complexity and cost. Data are presented that show a high negative correlation between cost and field reliability of avionics equipment. There is a paucity of research data on the relationships between simulator fidelity and transfer effectiveness. The results of the first and only recently completed experiment to investigate transfer of initial flight training as a function of simulator cockpit motion are summarized. A rational basis for simulator selection and use developed by Jacobs and Roscoe is presented. The need for research to establish relationships between transfer of training and physical characteristics such as degree and fidelity of simulation is seen as critical to the widespread future use of simulators for training and profit.

TRAINING, PROFIT, COST EFFECTIVENESS

The motivation for building and using aircraft simulators in the future can be for training or for profit, or it can be for a combination of training and profit. The primacy of one or another of these three possibilities will determine how widespread will be the future use of simulators in flying training and other skills training.

Historically, training has been an important concern of aircraft simulator purchasers and users. Profit has been an important concern of aircraft simulator builders and marketeers. Unfortunately, with few notable exceptions, simulator users have shown little concern for the "true" profit, if any, that can be derived from the use of simulators in training. Many have been fascinated and awed by the ever increasingly wonderful technological developments featured by the marketeers of successive generations of simulators. On the other hand, most simulator manufacturers and marketeers have shown little concern for the "true" training value of ever more sophisticated and therefore more costly and profitable (to them) simulator features.

The future of simulators in flying training and in other types of skills training can be extremely promising. We may even be witnessing now the beginnings of a revolution in skills training of all kinds. Heretofore impossible, this revolution can occur now because of recent behavioral science contributions to training technology and recent engineering contributions to systems simulation. However, the fulfillment of this bright promise is dependent upon the demonstration of cost effectiveness of simulators in skill training applications.

"Cost effectiveness," of course, is merely a concept that incorporates in an important and meaningful way our familiar goals of "training" and "profit." The importance of this concept lies in the fact that the profit to be realized refers to the training program rather than to the manufacturer. This is not to say that cost effective uses of simulators will not also be profitable to manufacturers. They will be. Conversely, however, unless considerably more attention is given to cost effective design and use of simulators by users and, more especially, by manufacturers, the manufacturers' profits may dry up. In another context I have stated, "Many of us who are professionally involved with the use of simulators in research and training are gravely concerned about the effects of some of the current activities in developing and selling simulators. The acquisition of simulators that cost several times as much to own and operate as their counterpart airplanes is certain to produce a backlash. Such a reaction will set back the desirable use of cost-effective simulators in reasonable research and training programs" (Hopkins, 1975).

We know quite a lot about the effectiveness of simulators in training programs. Almost any kind of simulator can be used effectively in a well-designed training program with specially trained instructors and highly motivated instructors and students. We can train effectively in some complex, costly, high fidelity simulators that almost approach perfect reproduction of certain of the aircraft characteristics. But we also can train effectively in quite simple, inexpensive simulators that may amount to little more than static mockups of the cockpit instruments and controls. We can even train effectively using a photograph of the cockpit instrument panel that depicts the displays and controls. Some primary flight training programs even emphasize the importance of "mental rehearsal" in the absence of any sensory input representing the aircraft's physical characteristics and dynamic responses as an effective aid in training.

In spite of the fact that we know that more or less effective training can be accomplished with a wide variety of types of simulators and related training devices, we don't know very much about how some of the specific features and characteristics commonly built into simulators contribute to or detract from the overall effectiveness of simulators used in training programs. The important issue is not how much fidelity of simulation can we achieve. The issue is not even one of how much fidelity of simulation do we need (regardless of cost in dollars, energy, and time). The important issue is what level(s) of fidelity and degree of simulation are cost effective.

Before dealing directly with a cost effectiveness analysis of a specific example of aircraft simulator fidelity let us consider an aspect of cost and effectiveness that is seldom mentioned in connection with simulators.

FIDELITY, COMPLEXITY, COST, RELIABILITY

As the degree and fidelity of simulation increase, the engineering complexity and the costs of the simulator rise at an increasing rate. This has implications far beyond the initial costs of complex simulators. One of these is perhaps best illustrated by the data in Figure 1 that show the relationship between unit production cost and field reliability for Air Force avionics equipment.

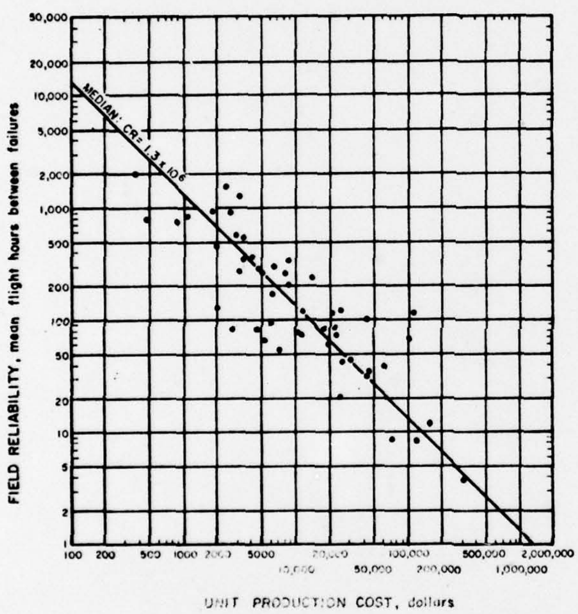

Figure 1. Avionics Field Reliability versus Unit Production Cost (Adapted from Gates, et al, 1974).

These data points were drawn from a number of sources in a study performed by the Institute for Defense Analyses for the Defense Advanced Research Projects Agency (Gates, Gourary, Deitchman, Rowan, and Weimer, 1974). Although these data are not based upon simulators they are based upon avionics equipments that are comparable to simulators in design complexity, type of components, and operational use and maintenance. The coefficient of correlation between reliability and cost calculated from the data points in Figure 1 is r = -0.8667. The linear regression accounts for 75.1% of the sample variance.

The authors of the report state:

As complexity increases, cost increases and reliability, as measured by mean flight hours between failures (MFHBF) decreases. Thus, [Figure 1] shows a median relationship in which

$$MFHBF = 1.3 \times 10^6/cost$$

From this relationship, field reliability of avionics can be crudely predicted (within a factor of 3) when cost is known. If, for example, an equipment costs $100,000, it can be expected to have an MFHBF of 13 hours; if it costs $1,000 the expected MFHBF is 1,300 hours.

The direct maintenance and repair costs associated with low mean hours between failure for a complex, costly simulator can be estimated in terms of dollars. The detrimental effects upon a training program of frequent disruptions due to equipment failure are less easily estimated or even appropriately expressed in terms of dollars.

FIDELITY AND TRANSFER EFFECTIVENESS

For some aircraft simulator features we know very little about how fidelity of simulation is related to training effectiveness. Unfortunately, certain of these features can be among the most costly ones to implement. A prime example is the case of simulator motion.

Transfer of training experiments have been performed in experimental psychological research for at least the past 118 years. Motion systems of varying degrees and fidelity of simulation have been available since the earliest Link trainers. In spite of all the research that has been done on transfer of training from ground-based simulators to aircraft over the past thirty years, the first experiment to investigate transfer of primary flight training from a ground based simulator to an aircraft as a function of simulator motion conditions was completed only one year ago (Jacobs and Roscoe, 1975). This research confirmed the results of the many experiments and informal observations that have shown ground-based flight simulator training to yield positive transfer to performance in flight. However, differences in transfer were not significant for groups of pilots trained with no simulator motion, normal-washout simulator motion, and random-washout simulator motion. A summary of the transfer data from this experiment is shown in Table 1.

TABLE 1

(From Jacobs and Roscoe, 1975)

Mean Times, Trials, and Errors to Reach Performance Criteria in the Airplane, Adjusted to Eliminate Individual Aptitude Effects, for a Control Group and Three Transfer Groups of Nine Subjects Each

	Control Group	Cockpit Motion Transfer Group		
	Airplane Only	Normal Washout	Fixed Base	Random Washout
Time in min	182.4	69.8	80.0	111.2
Errors	90.0	46.5	56.4	59.9
Trials	38.5	16.1	17.1	22.2

SIMULATOR COST EFFECTIVENESS

Jacobs and Roscoe (1975) provide an extensive discussion of the implications of these results for cost effectiveness of ground based simulator training. If simulator training reduces the time required for aircraft training sufficiently to be cost effective, then an overall training program should include simulator training. Overall training cost savings are realized when the simulator operating cost is less than aircraft operating cost by a ratio greater than the inverse of the transfer effectiveness ratio. The transfer effectiveness ratio (Roscoe, 1971) is determined as follows:

$$\mathrm{TER} = \frac{T_c - T_t}{X_t}, \text{ where}$$

T_c = time to criterion in the transfer task for the control group,

T_t = time to criterion in the transfer task for the experimental group,

X_t = time spent on the practice task in the simulator by the experimental group.

The inverse values of transfer effectiveness ratios for the different simulator motion groups used in the Jacobs and Roscoe experiment are 3.18 for normal washout motion, 3.35 for no motion, and 4.00 for random washout motion. Multiplying the inverse transfer effectiveness ratio of 3.18 by a typical hourly operating cost of $15.30 for a simple sustained pitch, bank, and yaw motion simulator yields a minimum airplane operating cost of $48.65 an hour for economical use of this kind of moving base simulator for training in the flight curriculum taught in this experiment. A similar calculation based on a typical hourly operating cost of $10.60 for a fixed-base simulator yielded a minimum airplane operating cost of $35.44 an hour for economical use of the fixed-base simulator. Since the typical cost of operating a primary training airplane is approximately $28.00 an hour, use of either type of simulator should be rejected as uneconomical if there were no other considerations. However, Jacobs and Roscoe point out a number of factors operating in the experiment that served to limit total transfer and transfer effectiveness. Nevertheless, this kind of analysis represents the approach that should be taken in determining the cost effectiveness of a simulator in a training program.

Jacobs and Roscoe also developed and presented a rational basis for simulator selection and use as follows:

Figure 2 depicts hypothetical relationships among incremental and cumulative transfer effectiveness and associated profit or loss as functions of the amount of training time in representative fixed-base and moving-base general aviation flight trainers. The scales of transfer, time and cost have been set to be consistent with the amount of training and findings of this study, but the relationships shown are of a generalizable nature, subject to scale adjustments to accommodate longer periods of training and higher levels of transfer effectiveness associated with better conditions for learning.

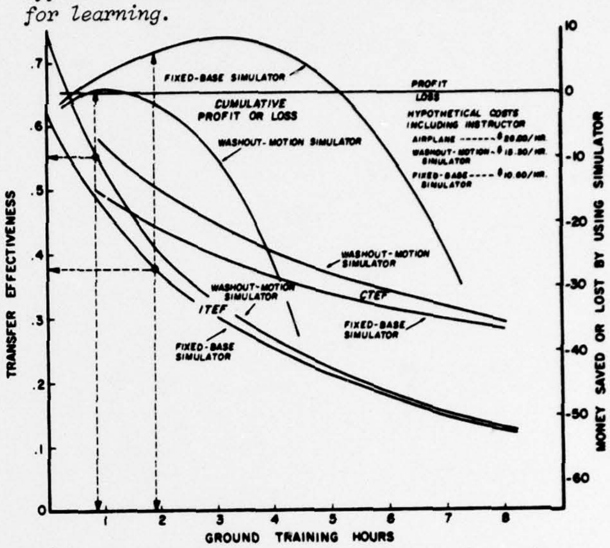

Figure 2. Hypothetical incremental and cumulative transfer effectiveness, in a 6.5-hr initial flight training curriculum, as functions (ITEF and CTEF) of the amount of training time in representative fixed-base and moving-base general aviation flight trainers and the associated profit or loss.

For a particular simulator, a cost effectiveness crossunder point is reached when its incremental transfer effectiveness ratio equals the ratio of its hourly cost to that of the counterpart airplane. With cost ratios of 0.546 and 0.379 between the two simulators and the airplane represented in Figure 2, corresponding incremental transfer effectiveness ratios are reached at slightly less than 1 hr and 2 hr, respectively, for this brief, 6.5 hr flight curriculum. Thus, in each cockpit motion condition, use of the simulator beyond these respective points would waste the time of the student, the instructor, and the simulator, all of which may be expressed in terms of money.

There is compelling evidence from the results obtained that the amount of simulator training given students in this experiment was uneconomical under the particular circumstances that prevailed. For a training simulator to be cost effective, its cost must be low, its transfer effectiveness high, and its use limited to the point at which its incremental transfer ratio crosses under its cost ratio relative to the airplane. (Jacobs and Roscoe, 1975).

TRAINING, PROFIT, AND RESEARCH

Near the beginning of this paper it was stated that the fulfillment of the bright promise for use of simulators in skills training is dependent upon the demonstration of their cost effectiveness in specific applications. Cost effectiveness can be achieved through a series of steps including specification and design of a simulator for the

purpose for which it is to be used and then using it at the proper phase and for the proper duration in the training program. However, the decisions for each of these steps must be based upon information derived from research. Most of the required research has not been done.

If simulators are to be widely used for training and profit in the future a systematic research program must be conducted to establish the relationships between transfer of training and physical characteristics such as degree and fidelity of simulation.

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Dr. Charles O. Hopkins is Head of the Aviation Research Laboratory, Professor of Psychology, and Professor of Aeronautical and Astronautical Engineering in the University of Illinois. He did his undergraduate studies at the University of Kentucky. After receiving his Ph.D. degree at the University of Illinois in 1952 he was Assistant Professor of Psychology in Tulane University for three years. He then held a number of positions, culminating in the position of Senior Scientist, during a 12-year period of employment with Hughes Aircraft Company. In 1967 he established the Human Performance Laboratory at McDonnell Douglas Corporation in St. Louis and served as manager of it until the fall of 1970, when he returned to the University of Illinois. Hopkins was President of the Human Factors Society in 1974 and has also served as that organization's Secretary-Treasurer.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The use of simulators for training and profit is discussed in terms of the concept of cost effectiveness. Increased degree and fidelity of simulation require greater equipment complexity and cost. Data are presented that show a high negative correlation between cost and field reliability of avionics equipment. There is a paucity of research data on the relationships between simulator fidelity and transfer effectiveness. The results of the first and only recently completed experiment to investigate transfer of initial flight

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